

USING TECHNOLOGY TO SUPPORT AIRCRAFT INSPECTION TRAINING

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ABSTRACT

Research in aircraft inspection and maintenance has revealed the criticality of human inspection performance in improving aviation safety. If we are to provide the general public with a safe and reliable air transportation system, inspection must be performed effectively, efficiently and consistently. Even though it is difficult to eliminate errors completely, continuing emphasis must be placed on identifying interventions to reduce errors and improve consistency in performance. Training has been identified as the primary intervention strategy in improving the quality and reliability of aircraft inspection performance. If training is to be successful, it is clear that we need to provide aircraft inspectors with tools to help enhance their inspection skills and improve performance. In response to this need, a high fidelity inspection-training simulator was developed: (ASSIST: Automated System of Self-Instruction for Specialized Training) - a specialized PC based inspection training software focused on improving aircraft inspection performance. Since then, a Virtual Reality (VR) based simulator has been developed as a collaborative extension of ASSIST. Both of these tools are described as part of this paper.

INTRODUCTION

Aircraft inspection and maintenance is essential to the safety of air transportation system. Training has been identified as the primary intervention strategy in improving inspection performance. If training is to be successful, we need to provide inspectors with training tools to help enhance their inspection skills. Existing training for inspectors in the aircraft maintenance environment tends to be mostly on-the-job training (OJT). However, this method may not be the best one (FAA, 1991; Gordon, 1994) because feedback may be infrequent, unmethodical, and/or delayed. Moreover, in certain instances feedback is

economically prohibitive or impractical because of the nature of the task. Because the benefits of feedback in training have been well documented (Weiner, 1975), and for other reasons as well, alternatives to OJT are sought.

More importantly, training for improving the visual inspection skills of aircraft inspectors is generally lacking at aircraft repair centers and maintenance facilities even though the application of training knowledge to enhance visual inspection skills has been well documented in the manufacturing industry where training has been shown to improve the performance of both novice and experienced inspectors (Weiner, 1975; Drury and Gramopadhye, 1990). Visual inspection skills can be taught effectively using representative photographic images showing a wide range of conditions with immediate feedback on the trainee's decision (Weiner, 1975; Blackmon and Gramopadhye, 1996), a combination of training methods that has also been shown to be superior to OJT alone (Latorella, et al., 1992). A case study presented by Gramopadhye, et al. (1998) showing how photographic images and feedback were used to develop a computer-based training program for a contact lens inspection task supports the findings of the Latorella, et al.

In the domain of visual inspection, the earliest efforts to use computers for off-line inspection training were reported by Czaja and Drury (1981). They used keyboard characters to develop a computer simulation of a visual inspection task. Similar simulations have also been used by other researchers to study inspection performance in a laboratory setting (e.g., McKernan, 1989). Since these early efforts, Latorella et al. (1992) and Gramopadhye, Drury and Sharit (1994) have used low fidelity inspection simulators using computer generated images to develop off-line inspection training programs for inspection tasks.

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Similarly, Drury and Chi (1995) studied human performance using a high fidelity computer simulation of a printed circuit board inspection. Another domain, which has seen the application of advanced technology, is that of inspection of x-rays for medical practice (Kundel, 1990). In summary, most of the work in the application of advanced technology to inspection training has focused on developing low fidelity simulators for running controlled studies in a laboratory environment. Thus, research efforts need to be extended in order to take full advantage of today's computer technology. Moreover, advanced technology has found limited application for inspection training in the aircraft maintenance environment. Presently, most of the applications of computer technology to training have been restricted to the defense industry for complex diagnostic tasks.

In light of this situation, a computer based training system focused on improving inspection skills for aircraft inspection tasks was developed as part of previous FAA funded efforts. These efforts yielded the ASSIST inspection-training software. A follow-up study conducted to evaluate the usefulness of ASSIST revealed that inspectors knowledge of the aircraft inspection task, inspection performance on a simulated aircraft inspection task and inspectors performance on real-world aircraft structural inspection task had improved significantly following training (Gramopadhye, Melloy, Chen, Bingham, Master, 2000).

Although ASSIST was developed in order to improve the visual search and decision-making skills of aircraft inspectors, the simulator lacks realism because it uses only two-dimensional images and does not provide a holistic view of the aft cargo bin. More importantly, the inspectors do not get the same look and feel of an actual inspection. Given the negative aspects of ASSIST, the concept of Virtual Reality (VR) technology was advanced as a solution, and in response a high fidelity Virtual Reality aft cargo bay simulator was developed at Clemson University (Duchowski et al., 2000). This paper begins with a literature review on training in aircraft inspection and later describes the development and use of the ASSIST and VR tools.

TRAINING

Patrick (1992) has identified training content, training methods and the trainee as the important components of the training program. Drury (1992) includes the training delivery system as another component. Training methods that have been used

effectively for aircraft inspection training (Drury and Gramopadhye, 1990; Gramopadhye et al., 1997) are described below.

1. *Pre-training.* Pre-training provides the trainee with information concerning the objectives and scope of the training program.
2. *Feedback.* A trainee needs rapid, accurate feedback in order to know whether a defect was classified correctly or a search pattern was effective. Gramopadhye, et al. (1997) classifies feedback as either performance or process feedback. Performance feedback typically consists of information on search times, search errors and decision errors. Process feedback, on the other hand, informs the trainee about the search process, such as areas missed.
3. *Active Training.* To keep the trainee involved in the training and to aid in internalizing the material, an active approach is preferred. In active training, the trainee actively responds after each new piece of material is presented, as, for example, in identifying a fault type. Czaja, et al. (1981) demonstrated the effectiveness of this approach for a complex inspection task.
4. *Progressive Parts Training.* In the progressive parts methodology, parts of the job are taught to criterion and then successively larger sequences of parts are taught.
5. *Schema Training.* Schema training lets the trainee generalize the training to new experiences and situations. For example, it is impossible to train an inspector on every site and extent of corrosion in an airframe. Thus, the inspector needs to develop a "schema" to allow a correct response to be made in unfamiliar situations. The key to the development of schema is to expose the trainee to controlled variability in training.
6. *Feedforward Training.* Feedforward training cues the trainee as to what should be perceived. For example, when novice inspectors try to find defects in an airframe, the indications may not be obvious, unless they know what to look for and where to look.

Training delivery systems

Training delivery systems can be classified as Classroom Training, On-the-Job Training and Computer-Based-Training (Gramopadhye et al., 1997). Gordon (1994), who develops a detailed taxonomy of delivery systems listing the advantages and disadvantages of each, indicates that the choice of the specific delivery system depends on such factors as the knowledge that needs to be transferred, the user's background and experience, the

implementation and development costs, the time available, and the flexibility.

Training methods along with an appropriate delivery system comprise an effective training system. The following section describes the use of these components and the task analytic methodology used to develop a computer-based aircraft inspection training program called the Automated System of Self Instruction for Specialized Training (ASSIST). Figure 1 shows the cover of the ASSIT CD.



Figure 1. Cover from the ASSIST Software

DESCRIPTION OF ASSIST

The computer-based training program was developed using Visual C++, Visual Basic and Microsoft Access. The development work was conducted on a Pentium 120 MHz platform with a 17" high resolution monitor, 32 MB RAM, 2 MB video RAM, ATI Mach 32 VLB advanced graphics accelerator card, 810 MB hard drive, multi-speed CD drive, 210 MB Bernoulli drive and a Reveal multimedia kit. The training program uses text, graphics, animation and audio. The input devices are a keyboard and a two-button mouse.

The overall structure of the ASSIST program is shown in Figure 2. ASSIST consists of three major modules: (1) the General Inspection Module, (2) the Inspection Simulation Training Module, and (3) the Instructor's Utilities Module. All system users interact through a user-friendly interface which capitalizes on graphical user interface technologies and human factors research on information presentation (e.g., color, formatting, layout, etc.), ease of use, and information utilization.

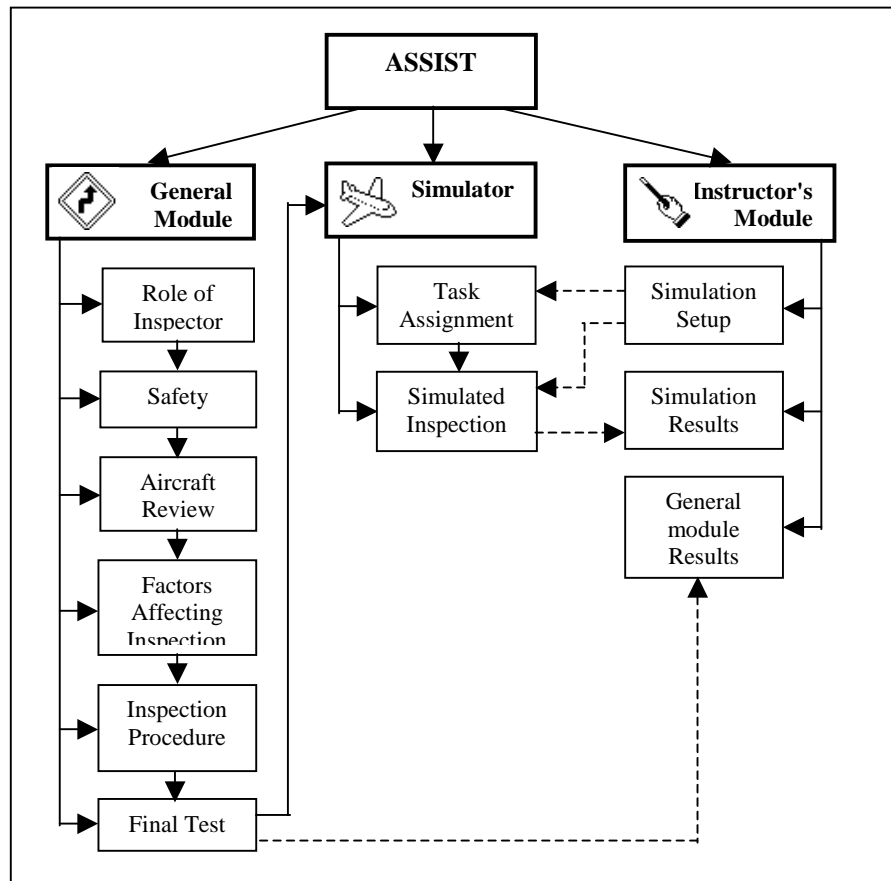


Figure 2. Components of the ASSIST aircraft inspector training program

General Module

The objective of the general module, which presents information through text, pictures, audio, and video, is to provide the inspectors with an overview of the following sub-modules (Figure 3): (1) role of the inspector, (2) safety, (3) aircraft review, (4) factors affecting inspection, and (5) inspection procedure. The module incorporates multimedia (sound, graphic, text, pictures and video) with interaction opportunities between the user and the computer.

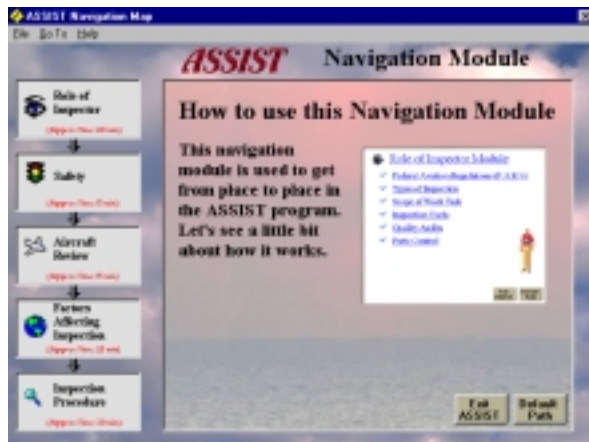


Figure 3. Navigation map in the General Module

Simulation Training Module

This module of the training program provides inspection training on a simulated aircraft inspection task: the aft cargo bin inspection of a Lockheed Martin L-1011 (Figure 4). By manipulating the various task complexity factors the instructor can simulate different inspection scenarios. The training module is further divided into four major sub-modules: introduction, search training, decision training and testing. Each sub-module uses computer-generated images of the airframe structure. The simulation module uses actual photographs of the airframe structure with computer-generated defects.

Introduction. The introduction provides the trainee with an overview of the various facets of the program, information on aircraft terminology and a representation of various faults. The section introduces the trainee to the search and decision making aspects of the visual inspection task. Each section is followed by a question and answer session wherein the trainee has to make an active response as each piece of new material is presented. The trainee is provided with immediate feedback as to its correctness. If an error is made, it is identified and the correct answer is supplied.

Search Training. The module trains the inspector on the search component of the visual inspection task. The objective is to train inspectors to correctly identify and locate defects. This type of training is aimed at developing cues, knowledge of where specific defects occur, and the use of feed-forward information. The trainee is provided with immediate feedback on the following speed and accuracy measures: the time to locate the defect (search time), and the accuracy of the search process (the program lets the inspector know whether he/she correctly identified the defect and marks the defect on the computer screen).

Decision Training. This module trains the inspector on the decision making component. A series of aircraft structures are displayed with the faults marked. After each image is displayed, the inspector makes an active response. First, the trainee classifies the defect by defect name. Following defect classification, the trainee writes up a Non-Routine Report- NRR report (if required) based on the number of defects, defect type, severity and location. The inspector is provided with immediate feedback on his or her decision making performance. The general objective of this module is to train the inspector on both the rule-based and knowledge-based aspects of the decision component of the inspection task.

Testing. The testing module is designed to operate in two separate modes: with and without feedback. The non-feedback mode simulates the actual visual inspection task (as it would take place on a hangar floor). In either mode, the inspector first locates the defect and indicates this by clicking on the fault. Subsequently, the inspector classifies the defect. In the feedback mode, the inspector is provided with immediate feedback on his/her performance on the search and decision-making components of the inspection task (Figure 5). The trainee is also provided with end-of-session performance feedback.



Figure 4. The Simulator from the Inspection Module



Figure 5. Feedback information given by ASSIST

Instructor's Utilities Module and Start-up Module

The Instructor Utilities Module allows the supervisor/instructor to access the results database, the image database and the inspection parameter modules. The start-up module allows the instructor to select images from the image database and store them in a batch file for use with the inspection simulator.

ADVANTAGES OF ASSIST

The high degree of control that ASSIST affords creates the opportunity to systematize the training. In addition, there are several other inherent advantages that serve to alleviate the problems characteristic of OJT:

Completeness. Inspectors can be exposed to a wide variety of defects, with varying degrees of severity, at different locations, through the use of a library of defect images. Inspectors can also be trained on less frequently occurring critical defects.

Adaptability. ASSIST can be modified to meet the needs of individual inspectors. Batch files of images can be created to train inspectors on particular aspects of the inspection task with which they have the greatest difficulty. Thus, the program can be tailored to accommodate individual differences in inspection abilities.

Efficiency. Since the training will be more intensive, the trainees will be able to become more skilled within a shorter period of time.

Integration. The training system will integrate different training methods (e.g., feedback training,

feed-forward training, and active training) into a single comprehensive training program.

Certification. ASSIST can be used as part of the certification process. Since the record keeping process can be automated, instructors can more easily monitor and track an individual's performance, initially for training and later for retraining.

Instruction. ASSIST could be used by instructors in FAA certified A&P school for training. In this manner, for example, aircraft maintenance technicians could gain exposure to defects on wide-bodied aircraft that they might not have otherwise.

The paper has described research in the area of aviation maintenance and inspection currently underway at Clemson University. Through the development and systematic application of human factors techniques, the research aims at improving the effectiveness and efficiency of aircraft visual inspection. The results of the research effort have been made available to the aviation maintenance community as deliverable products in the form of usable CD-ROMs. It is anticipated that the use of these products would lead to improved airworthiness of the U. S. domestic aircraft fleet. Subsequent phases of this research will evaluate the utility of ASSIST in an operational setting. Finally, this research has future implications as well. Human performance models could potentially be used in conjunction with ASSIST for a wide range of controlled studies to both 1) evaluate the effect of various task and subject factors on aircraft inspection performance, and 2) identify specific interventions to enhance performance.

DESCRIPTION OF VR TOOL

The primary rendering engine is a dual-rack, dual-pipe, SGI Onyx2® InfiniteReality™ system with 8 raster managers and 8 MIPS® R10000™ processors, each with 4Mb secondary cache. It is equipped with 3Gb of main memory and 0.5Gb of texture memory. Multi-modal hardware components include a binocular ISCAN eye tracker mounted within a Virtual Research V8 (high-resolution) Head Mounted Display (HMD). The V8 HMD offers 640×480 resolution per eye with separate left and right eye feeds. HMD position and orientation tracking is provided by an Ascension 6 Degree-Of-Freedom (6DOF) Flock Of Birds (FOB), a D.C. electromagnetic system with a 10ms latency. A 6DOF tracked, hand-held mouse provides a means to represent a virtual tool for the user in the environment. Figure 6 shows a user wearing the eye tracking HMD.

Eye images captured by the cameras can be seen in two video monitors near the lower right of the figure.

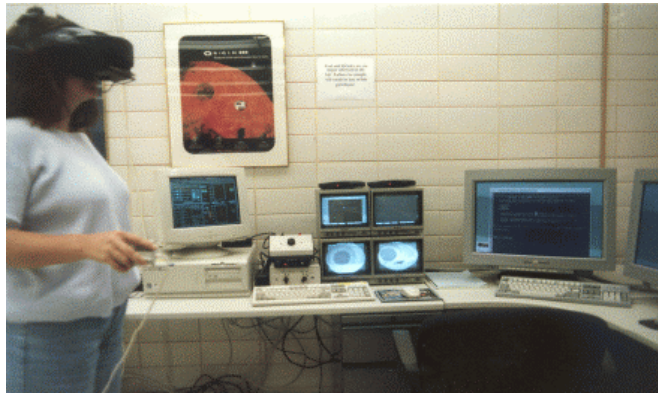


Figure 6. Eye tracking HMD

The goal of the construction of the virtual environment was to match the appearance of the physical inspection environment, an aircraft cargo bay, shown in Figure 7.



Figure 7. Aircraft cargo bay physical environment

The physical environment is a complex three-dimensional cube-like volume, with airframe components (e.g., fuselage ribs) exposed for inspection. A typical visual inspection task of the cargo bay involves carefully walking over the structural elements while searching for surface defects such as corrosion and cracks (among others).

Model Geometry

The evolution of the virtual inspection environment began with a straightforward emulation of the two-dimensional ASSIST inspection grid. The rationale for this design was the relatively quick development of a simple texture-mapped grid to provide the user with a

more natural representation and navigation of the entire inspection region.

The image grid, displayed as a flat polygonal wall in VR, is shown in Figure 8. Although the VR environment provided advantages over the PC-based system, several problems with its design became evident.



Figure 8. Initial planar 2D virtual environment

The main advantage of the VR system is its display of the entire side of the airframe's wall, which provides better context for the user in terms of the location of the individual panels under inspection. The obvious drawbacks of this implementation, however, are the noticeable discrepancies in the appearance of the images (e.g., lighting changes and positional misalignment), and overly simplistic geometry, which is not well suited for a Virtual Reality application. The 2D wall in effect defeats the immersive and natural navigational advantages offered by VR technology. Clearly, to provide an immersive environment, a three-dimensional structure was required.

The next evolution of the inspection environment was patterned after a simple three-dimensional enclosure (e.g., a cube), specified by actual dimensions of the real inspection environment, i.e., an aircraft's cargo bay. An early stage of the wireframe rendition of the cargo bay "3D box" is shown in Figure 9.

The model is built entirely out of planar polygons. There are two pragmatic reasons for this design choice. First, since the representation of the true complexity of the airframe structure is avoided, fast display rates are maintained (on the order of 10-30 fps) while tracking latencies are minimized (on the order of 10-30 ms for head and eye trackers). Second, planar polygons (quadrilaterals) are particularly suitable for texture mapping. To provide a realistic appearance of the

environment, in keeping with the desire of preserving geometric simplicity, images of the physical environment are used for texture maps.

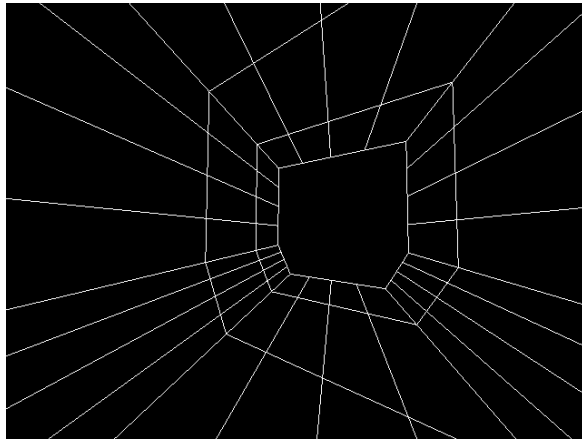


Figure 9. 3D box-like virtual environment

Lighting and Flashlight Modeling

The SGI Onyx2 host provides real-time graphics rendering performance, while simultaneously processing tracking information sent to the host via the rs-232 serial connection. To generate the environment, no specialized rendering algorithms are invoked beyond what is provided by the OpenGL graphics library Application Program Interface (API). Standard (1st-order) direct illumination is used to light the environment. Additionally, an OpenGL spotlight is used to provide the user with a “virtual flashlight”. The flashlight effect is shown over a 2D polygon in Figure 10. The flashlight's position and orientation are obtained from the 6DOF electro- magnetically tracked “flying mouse” from Ascension.



Figure 10. Virtual flashlight shown over a 2D polygon

Because OpenGL relies on the Phong illumination model coupled with Gouraud shading to generate lighting effects, large polygons produce a coarse (blocky) flashlight beam. To correct this problem, the polygons were subdivided to smooth out the spotlight, producing a more aesthetically pleasing circular effect. The level of polygonal subdivision is user-adjustable.

Realistic Texture Maps

To texture map the simple 3D box-like environment, images of the physical environment were obtained. With permission from a commercial airline, images of an aircraft's cargo bay were taken while the aircraft was withheld from operation for inspection and servicing. Since the time to photograph the cargo bay interior was limited, no particular methodology or special equipment was used to obtain these images. Care was taken to attempt to photograph the environment in sections by translating a hand-held camera, however, inaccuracies in image alignment were inevitable.

In retrospect, a better approach would have been to measure the environment *a priori*, then calculate and record appropriate positions of the camera, and ensure proper placement of the camera on some stable rigging apparatus (e.g., a leveled tripod fastened to the aircraft interior). This approach would be similar to a motion capture or an image-rendering session used in special effects production work. Of course, this method would require more time and care to carry out.

Although our approach was somewhat haphazard, image alignment was possible through careful labeling of photographs and a good deal of digital post-processing. In our case, we used The Gimp (the freeware analogue of PhotoShop) to orient and resize the images appropriately. The resulting environment, with the user-held “virtual flashlight” is shown in Figure 11.

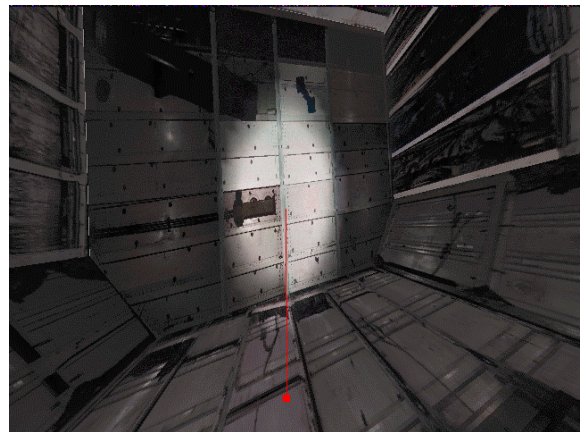


Figure 11. Virtual flashlight in virtual cargo bay environment

CONCLUSIONS & FUTURE WORK

The paper outlines how PC based technology (ASSIST) and later enhanced using VR technology can be used to realistically simulate the aircraft inspection environment. The platform is based on high-end graphics engines and an electro magnetically tracked, binocular helmet equipped with infrared eye tracking capability. Rendering techniques are relatively simple, relying only on standard (OpenGL) graphics library calls. Tracking routines deliver helmet position and orientation in real-time, which are used directly to provide updated images to the HMD. The use of a VR based inspection environment will enable us to conduct controlled studies off-line, to understand human performance in inspection. Results obtained from these studies will yield interventions, which can be used to improve aircraft inspection performance and ultimately, aviation safety.

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